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# TECHNICAL NOTE

## D-372

A FLIGHT STUDY OF THE CONVERSION MANEUVER  
OF A TILT-DUCT VTOL AIRCRAFT

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SUMMARY

Flight records are presented from an early flight test of a wing-tip mounted tilting-ducted-fan, vertical-take-off and landing (VTOL) aircraft configuration. Time histories of the aircraft motions, control positions, and duct pitching-moment variation are presented to illustrate the characteristics of the aircraft in hovering, in conversion from hovering to forward flight, and in conversion from forward flight to hovering.

The results indicate that during essentially continuous slow level-flight conversions, this aircraft experiences excessive longitudinal trim changes. Studies have shown that the large trim changes are caused primarily by the variation of aerodynamic moments acting on the duct units. Action of the duct-induced downwash on the horizontal stabilizer during the conversion also contributes to the longitudinal trim variations.

Time histories of hovering and slow vertical descent in the final stages of landing in calm air show angular motions of the aircraft as great as  $\pm 10^\circ$  about all axes. Stick and pedal displacements required to control the aircraft during the landing maneuver were on the order of 50 to 60 percent of the total travel available.

INTRODUCTION

In a continuing effort to provide data for developing flying qualities criteria and to define the basic characteristics of various types of aircraft, the National Aeronautics and Space Administration is currently obtaining flight data during the early trials of the VTOL test aircraft recently constructed. The first of these vehicles on which flight data were obtained was a tilt-wing type of aircraft. The results of some of the early flight trials with the tilt-wing aircraft are presented in reference 1. Some preliminary data have now been obtained on a second VTOL configuration to reach the flight-test stage. The data reported herein are from manufacturer's flight tests of a tilting ducted-fan type of aircraft (the Doak 16).

One problem area being studied in the VTOL concept is the conversion flight region between hovering and conventional airplane flight. The flight characteristics of the tilt-duct VTOL test bed during conversion from hovering to forward flight have been documented by data obtained in flight with recording instrumentation. Some of these flight records were analyzed and are incorporated herein to show characteristics that must be considered in future designs of this type.

The flight records utilized herein were obtained with the cooperation of Doak Aircraft Company, Incorporated.

## APPARATUS AND PROCEDURE

### Aircraft

The vertical-take-off-and-landing flying test bed shown in figures 1 and 2 is similar in configuration to a conventional airplane, with the exception that a tilting-ducted-fan assembly is mounted at the tip of each wing. The thrust axis of the ducted fan can be rotated from a position perpendicular to the wing-chord plane for hovering to a position essentially parallel to the wing chord for high-speed flight. The physical dimensions of the aircraft for this investigation are given in table I.

The ailerons, elevator, and rudder are actuated in normal fashion for the forward-flight configuration. A single switch on the top of the control stick is used for duct rotation during the conversion. For roll control in hovering flight and during the conversion process, the lateral stick motions actuate guide vanes arranged radially in each duct inlet. The actuation of these guide vanes changes the effective angle of attack of the fan blades, and thereby changes the thrust output. The design of the duct inlet-guide-vane control is such that lateral stick motions cause a maximum guide-vane pitch change when the ducts are set for vertical flight, and the same motions cause correspondingly less change as the ducts are rotated toward the forward-flight position. When the ducts are rotated fully to the forward-flight position, lateral stick displacements cause no guide-vane motion.

The cruciform tail vanes in the engine-exhaust exit (shown in fig. 2) are used for pitch and yaw control during hovering. These cruciform tail vanes are not phased out as the ducts are rotated. A long stainless-steel tail pipe directs the turbine exhaust gases over the tail vanes. These vanes are of three-piece articulated design. (See fig. 2.) Height control is accomplished in the hovering configuration by variation in rotational speed of the fixed-pitch ducted fans. A vernier adjustment is provided at the engine power control for this purpose. The horizontal

stabilizer can be varied through  $11^\circ$  to help offset the nose-up pitching moment encountered during conversions.

### Instrumentation

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The airspeed, pressure altitude, angle of attack, duct angle, engine-output shaft speed, horizontal-stabilizer angle, and engine gear-box oil pressure (provides torque output reference) are recorded by two motion-picture cameras photographing the pilot's instrument panel. The duct forces and moments are sensed by strain-gage bridges mounted on the duct support trunnion and recorded on a 14-channel oscillograph as an axial-force component (thrust), normal-force component, and moment tending to rotate the duct (pitching moment). Also recorded on the oscillograph are the aircraft angular velocities about the roll, pitch, and yaw axes, as well as lateral-, longitudinal-, and directional-control positions.

### Test Conditions and Procedures

The data obtained during test flights of the tilt-duct aircraft included approximately level-flight conversions from hovering to forward flight, from forward flight to hovering, and a hovering descent to the landing condition. The ground altitude at the test site was approximately 2,200 feet. The data on the conversion-flight regime presented herein were obtained during the first conversion flight at low altitude (between 50 and 100 feet above the ground) representative of VTOL operation. Earlier conversion flights had been made, however, by the same pilot at altitudes of several thousand feet. These flights and conversion flights made by NASA pilots subsequently to the one for which data are presented herein indicate qualitatively similar characteristics. It is believed, therefore, that the data obtained are typical for the aircraft.

Time histories of representative conversion-type maneuvers were obtained by direct readings of the records at regular time intervals plus between-point fairings based on detailed inspection of the records in the zones between the points. The time histories with the data points shown were obtained from motion pictures of the pilot's panel taken at two frames per second; other time histories were taken directly from continuous oscillograph records.

It should be noted that the magnitudes of the duct moments shown herein include the relieving moments resulting from the duct drive shaft torque and are thus applicable from a standpoint of structural load in the support mechanisms. In order to obtain the aerodynamic moment acting on the aircraft, for design needs such as estimating aircraft trim variations caused by each duct, the values of duct moment shown must be increased in the nose-up direction by an amount equal to the torque in

the duct drive shaft. For rated power (430 horsepower per duct) at maximum engine output speed, the relieving moment amounts to approximately 475 foot-pounds.

## RESULTS AND DISCUSSION

### Conversion From Hovering to Forward Flight

Time histories during the conversion from hovering to forward flight of velocity, duct angle, horsepower, pressure altitude, elevator position, duct moment, angle of attack, and horizontal stabilizer angle are shown in figure 3. The conversion from hovering to forward flight was completed in 11 seconds, a minimum amount of time for this aircraft (it takes a minimum of 11 seconds to rotate the ducts  $90^\circ$ ); power changes were smooth, and the control deflections, although judged to be excessive, were not intolerable. The altitude against time curve shows a continuous increase throughout the accelerating condition, indicating that the aircraft is capable of complete conversion during an uninterrupted climb-out from the take-off point. During this conversion only about 30 percent of the available longitudinal control was used to maintain continuous level flight. It should be noted, however, that the maximum nose-down trim setting of the horizontal stabilizer was used to help offset the nose-up pitching moment.

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### Conversion From Forward Flight to Hovering

In the conversion from forward flight to near hovering, the time histories of velocity, duct angle, horsepower, pressure altitude, elevator position, duct moment, angle of attack, and horizontal stabilizer angle are shown in figure 4. The decelerating conversion from forward flight to near hovering was completed in approximately 1 minute, much slower than the accelerating conversion. During this conversion a large amount of forward stick trim change was experienced in an attempt to maintain continuous level flight. It can be seen that at a time of 60 seconds, the stick was against or close to the forward stop, and the angle of attack was  $10^\circ$  to  $15^\circ$ . The maximum aircraft nose-down trim setting of the horizontal stabilizer was used to help offset the nose-up pitching moment. The nose-down attitude of the aircraft (negative angle of attack) over a period of 25 seconds, in which the aircraft drag was kept low, resulted in a relatively long time for deceleration during this conversion. If a faster deceleration were made, however, it would be expected that higher duct pitching moments would result and require more forward change in the position of the stick than did the nose-down technique. The maximum moment encountered on each duct was about 1,700 foot-pounds and lasted for about 31 seconds through a velocity range of 100 to 50 knots and a duct angle range of  $30^\circ$  to  $60^\circ$ . It should be noted again that the measurements of duct pitching moments shown herein

include the relieving effects of the torque in the duct drive shaft; thus the magnitude of aerodynamic moments tending to cause the aircraft to nose up are greater than the values shown in this figure by amounts up to about 475 foot-pounds at rated power and rpm. From these data it is indicated that the most severe design condition from a standpoint of design loads and trim requirements of a ducted-fan configuration occurs during the decelerating conversion where the ducts experience a large angle of attack at relatively high airspeeds. Although the aerodynamic moments acting on the ducts appear to be the primary cause of the longitudinal trim variations, another factor is the action of the duct-induced downwash on the horizontal stabilizer.

### Hovering and Vertical Descent to Landing

During the hovering and vertical descent to the landing condition, the time histories of control position movements and angular velocities about the three axes are shown in figure 5. It should be noted that even though these data were taken under calm air conditions, large control motions (sometimes as much as 50 to 60 percent of the total available control travels) were used to control the attitude of the aircraft and hold it over the intended landing spot. By integration of the angular velocity traces it can be found that angular displacements of the aircraft as much as  $\pm 10^\circ$  from the trim attitude are experienced about all axes. It is not possible to determine from the time histories of the control motions and aircraft angular velocities whether the large, erratic aircraft motions are induced by excessive control manipulation in this first conversion at low altitudes (i.e., 50 to 100 ft) or whether the large control motions result from an effort by the pilot to correct excessive uncontrolled-for (not pilot induced) motions of the aircraft. Later flights by NASA pilots, however, tend to show that the large control motions were necessary to correct uncontrolled-for motions of the aircraft.

### CONCLUDING REMARKS

The preliminary study of flight records taken during conversion maneuvers performed by the tilt-duct aircraft under favorable wind conditions indicated the following conditions:

1. Results obtained during conversion from hovering to forward flight indicate that this condition provides the most desirable flying qualities of the three conditions studied. The ducts were rotated to  $0^\circ$  continuously in the minimum amount of time, power changes were smooth, and the control deflections, although judged to be excessive, were not intolerable. The altitude against time curve shows a continuous increase

throughout the accelerating condition, indicating that the aircraft is capable of complete conversion during an uninterrupted climb-out from the take-off point.

2. The results obtained during conversion from forward flight to hovering indicate that this maneuver represents the largest problem area, insofar as the practical operational standards for transition flying are concerned. The most apparent of the difficulties encountered in this maneuver was the excessive longitudinal trim change caused by variation of aerodynamic moments acting on the duct. Action of the duct-induced downwash on the horizontal stabilizer also contributes to the longitudinal trim variations.

3. During hovering and vertical descent to landing, results indicated angular displacements of the aircraft of  $\pm 10^\circ$  about the three axes. Plots of control positions show that as much as 50 to 60 percent of the total available control travel was used to control the aircraft during hovering in calm air.

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Langley Research Center,  
National Aeronautics and Space Administration,  
Langley Field, Va., January 26, 1960.

#### REFERENCE

1. Thomas, Lovic P., III: A Flight Study of the Conversion Maneuver of a Tilt-Wing VTOL Aircraft. NASA TN D-153, 1959.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRCRAFT

Ducted propellers:	
Diameter, ft . . . . .	4
Number of blades (each fan) . . . . .	8
Ducts:	
Inside diameter, ft . . . . .	4
Chord, ft . . . . .	2.75
Rotation, deg . . . . .	92
Wing:	
Span (excluding ducts), ft . . . . .	16
Overall span, ft . . . . .	25.3
Mean aerodynamic chord, ft . . . . .	5.89
Airfoil section (modified) . . . . .	NACA 2418
Taper ratio . . . . .	0.747
Sweep, deg . . . . .	0
Dihedral, deg . . . . .	0
Area, sq ft . . . . .	96
Area of each aileron, sq ft . . . . .	6.2
Vertical tail:	
Height (approximate), ft . . . . .	4.8
Average chord, ft . . . . .	2.55
Airfoil section (modified) . . . . .	NACA 0012
Area, sq ft . . . . .	13.9
Horizontal tail:	
Area, sq ft . . . . .	28.5
Airfoil section (modified) . . . . .	NACA 0012
Span (projected) . . . . .	11.6
Dihedral, deg . . . . .	10
Fuselage length (approximate), ft . . . . .	28.7
Overall length (approximate), ft . . . . .	31
Engine . . . . .	LYCOMING YT-53-I-1
Weight as flown (approximate), lb . . . . .	3100
Center of gravity:	
Forward, percent M.A.C. . . . .	25
Rearward, percent M.A.C. . . . .	32



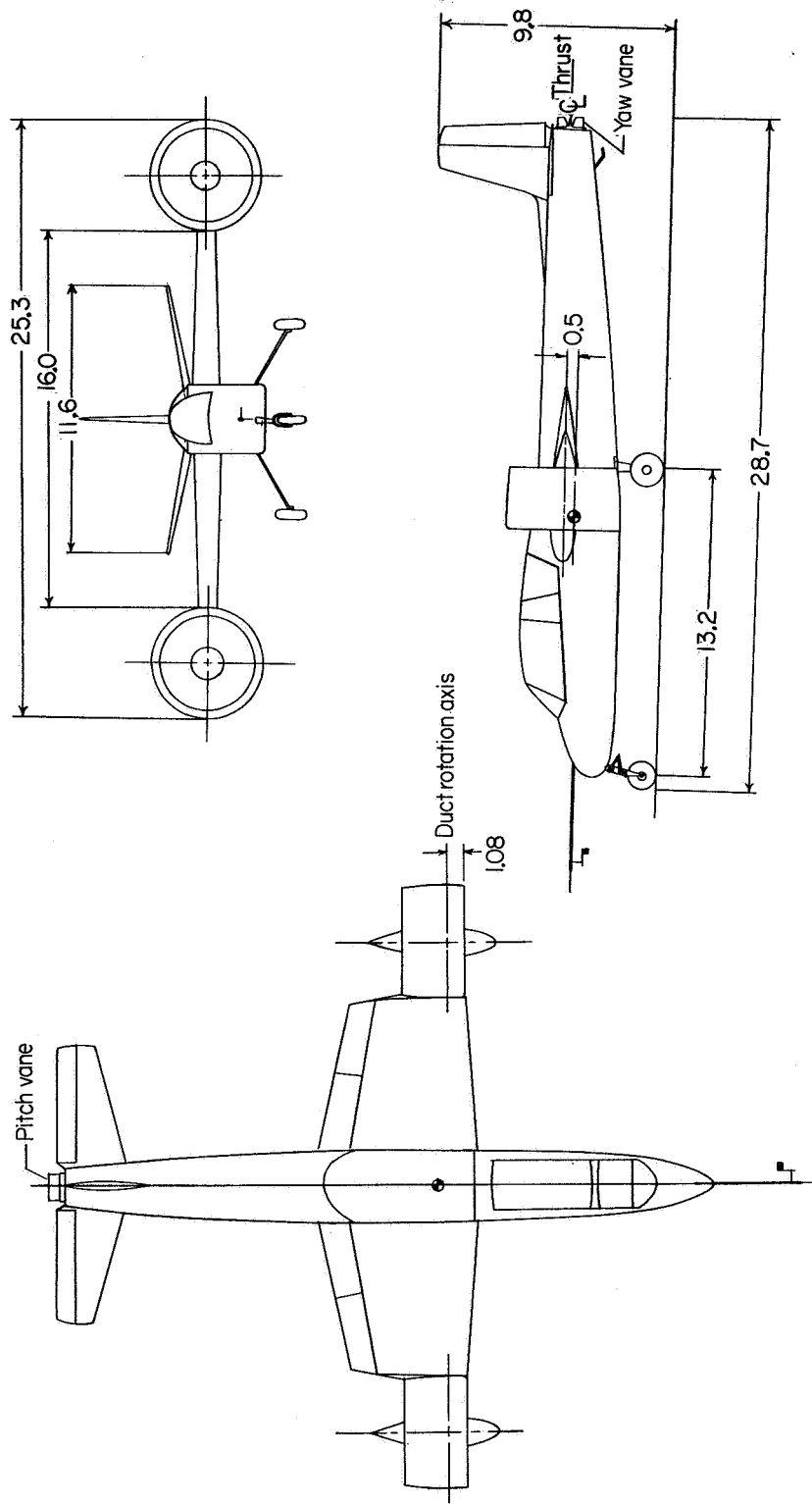


Figure 1.- Sketch of tilt-duct VTOL aircraft. (All dimensions in feet.)

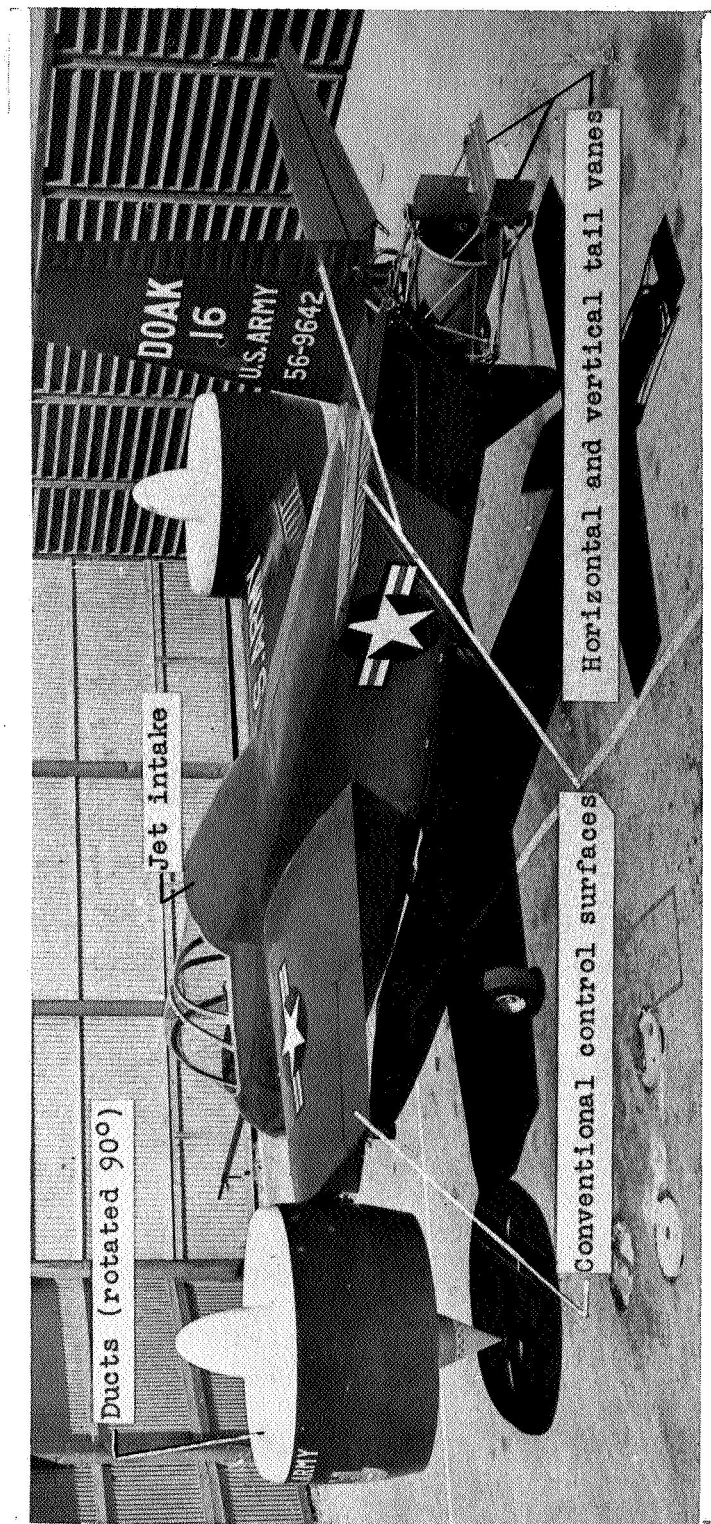


Figure 2.- View of tilt-duct VTOL aircraft. L-60-209

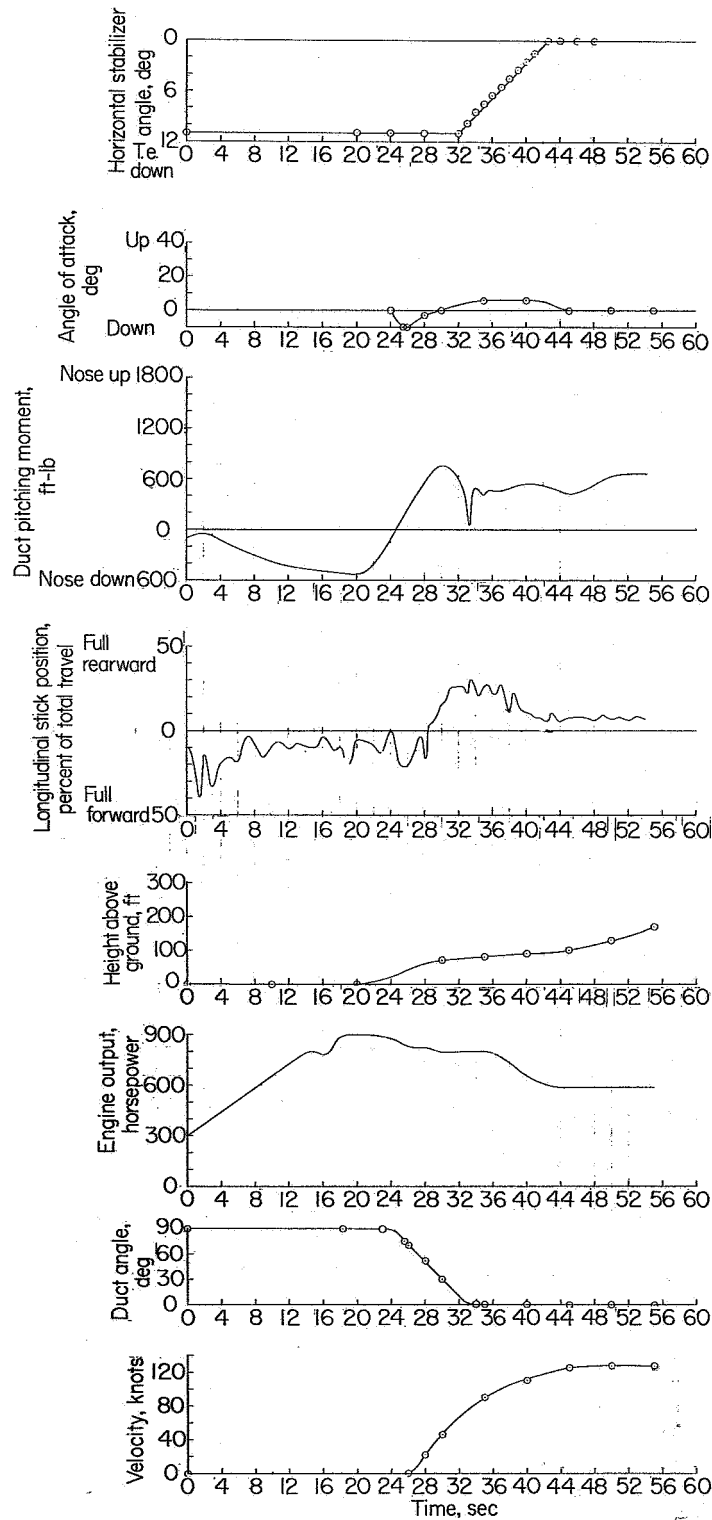


Figure 3.- Time history of hovering to forward flight.

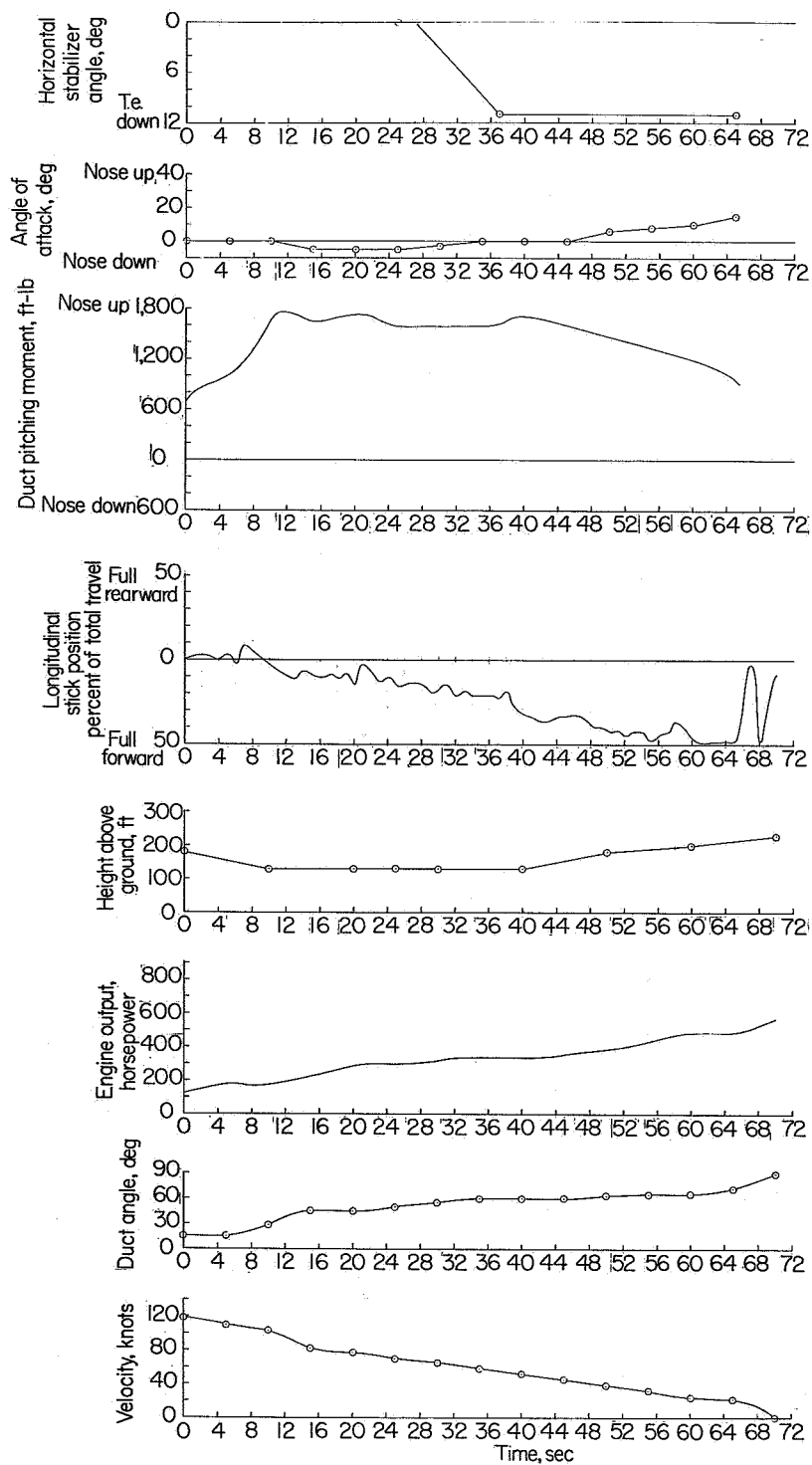


Figure 4.- Time history of forward flight to hovering.

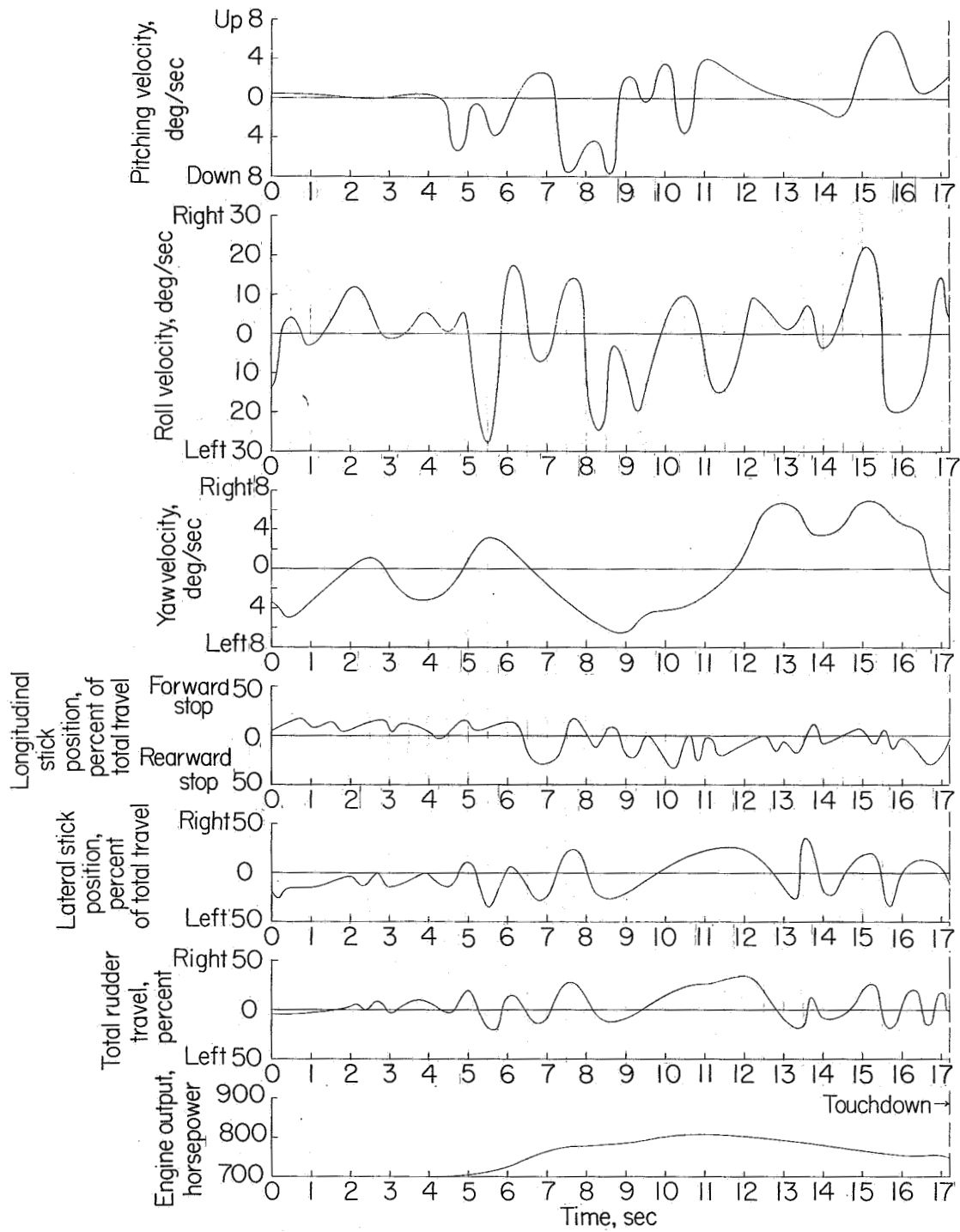


Figure 5.- Time history of hovering descent from approximately 100 feet altitude to touchdown.